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Vegetative production of kenaf and canola under irrigation in central California☆

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Abstract

Kenaf (*Hibiscus cannabinus* L.) and canola (*Brassica napus* L.) are potential alternative crops for forage production and phytoremediation adaptable to irrigated agriculture in central California. However, little information is available on the water requirements for growing these crops under irrigated conditions, particularly with regard to increasing their vegetative growth. A 3-year field study was undertaken to evaluate kenaf (cultivars: 7-N, Everglades-41, Tainung-2 and breeding lines: C-531, C-533) and one variety of canola (Westar) for potential cultivation. Kenaf was grown as a spring crop and canola was grown as a fall crop. Plants were irrigated at five different levels, ranging from 368 to 1413 mm for kenaf and from 62 to 359 mm for canola per growing season. For kenaf, shoot and root dry matter (DM) production increased as irrigation was increased incrementally from 25 to 125% crop evapotranspiration (Et_c); water application at 150% Et_c had no increased benefit. Bark:core ratio of the various kenaf cultivars, however, was unaffected by the level of irrigation. For canola, shoot DM and leaf:stem ratio increased with irrigation up to 125% Et_c, whereas root DM did not differ significantly among irrigation treatments. Kenaf produced at least twice as much biomass as canola and both crops produced maximum vegetative yields at 100–125% Et_c in central California.

Keywords: Kenaf; Canola; Irrigation; Vegetative growth; Evapotranspiration

1. Introduction

New crops with high water utilization efficiency and increased drought tolerance are being sought for production in arid regions of the western US (Howell, 2000). Two plant species with excellent potential as alternatives to more traditional crops grown under irrigated conditions are kenaf and canola. Both species grow well in dry environments and can tolerate moderately saline soil conditions (Bañuelos et al., 1997; Stricker et al.,

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1997). Kenaf is a member of the cotton (Malvaceae) family and has been suggested by several researchers for use as both fiber and fodder (Taylor, 1992; Webber, 1993; White et al., 1994). The stem of this plant contains two distinct fibers, the bark or outer bark fibers and the inner core fibers, both of which can be used in pulp production (White et al., 1970). The quality of the pulp equals or exceeds the quality of many standard wood fibers (Theisen et al., 1978). The ground leaves of kenaf have high digestibility and can be used as a source of roughage and protein for cattle and sheep (Hays, 1989; Webber, 1993). Canola is a member of the mustard (Brassicaceae) family and has become one of the most important sources of vegetable oil in the world (Alberta Agriculture, 1980). Its oil also has potential in the developing biodiesel market (Economic Research Service, 1996). In addition to oil production, the leaves and stems of canola provide high quality forage because of its low fiber and high protein content (Wiedenhoeft and Bharton, 1994) and can be milled into animal feeds.

Little information is available in the literature on the water requirements for growing kenaf and canola under irrigated conditions, particularly with regard to increasing their vegetative growth. Irrigation studies on these plants have focused on improving fiber production in kenaf (Muchow and Wood, 1980; Bhangoo et al., 1986; Robinson, 1988; Bhangoo and Cook, 1995) or on increasing seed yields in canola (Clarke and Simpson, 1978; Prihar et al., 1981; Lewis and Thurling, 1994; Boochereau et al., 1996; Champolivier and Merrien, 1996). Because both kenaf and canola can produce a great amount of vegetative biomass, researchers are seriously evaluating the capability of both plant species to accumulate high levels of selenium (Se) in their leaves (Bañuelos et al., 1997). With greater leaf yields, more Se can be extracted from the soil and stored in the leaves. Moreover, the nutritional value of the leaves enriched with Se make both plant species ideal candidates as alternative forage crops. The objective of this study was to determine the optimal level of irrigation for maximizing vegetative growth of kenaf and canola planted in the San Joaquin Valley of central California (latitude 36°46′N and longitude 119°43′W). Kenaf was grown as a spring crop, whereas canola was grown as a winter crop. Although most growers would irrigate these crops using flood or furrow irrigation, subsurface drip irrigation was used in this study to minimize errors caused by evaporation, runoff and deep percolation when estimating crop water requirements (Phene et al., 1990).

2. Materials and methods

Irrigation studies were conducted on kenaf (*Hibiscus cannabinus* L.) and canola (*Brassica napus* L.) on a 0.25-ha field located in Fresno, CA. Kenaf was planted on April 15, 1995, April 18, 1996 and April 16, 1997, whereas canola was planted on October 15, 1994, October 20, 1998 and October 1, 1999. Soil at the site was a Hanford sandy loam (mixed, nonacid thermic typic Xerothents). Seeds from kenaf cultivars 7-N (released as Dowling), Everglades-41 and Tainung-2 and breeding lines C-531 and C-533, and one variety of canola (Westar) were sown at a density of $\approx 160{,}000$ plants ha^{-1}. The beds were 12 m long and 1.52 m wide. Each bed contained two planted rows spaced 0.3 m apart. The field was cleaned of plant refuse and treated with Trifluralin (α,α,α-trifluro-2,6-dinitro-*N*, *N*-dipropyl-*p*-toluidine) herbicide (0.5 l ha^{-1}) and 15-15-15 NPK granular fertilizer (56 kg ha^{-1}) incorporated into the upper 10 cm of soil before planting. Plants were established with sprinkler irrigation of 50 mm at 25 days prior to planting, 25 mm of water at time of planting and 25 mm of water at 10 days after planting.

Irrigation treatments were initiated after plant roots appeared well established. Because a crop coefficient did not exist for kenaf, we approximated Et_c for kenaf in this study by multiplying reference grass evapotranspiration (Et_o) reported by the California Irrigation Management Information System (CIMIS) (Howell et al., 1984) by a crop coefficient (K_c) for cotton (Allen et al., 1998). Cotton was selected because it is considered a high water user, planted and harvested for vegetation at the same time as kenaf and it has clear growth stages that we could pattern our initial, mid- and end-season K_c values. The reported K_c values for canola by Allen et al. (1998) were similarly used to create an Et_c for canola in this study. Both Et_c values created for kenaf and canola were only intended to be used as reference values for developing our water treatments in this study. Both kenaf and canola were irrigated at five different levels designated as 25, 50, 100, 125 and 150% of potential crop Et_c with subsurface drip tubing (GeoFlow, Inc., Charlotte, NC) centered in the beds at 40 cm depth. In the field, the actual Et_c values used for kenaf and canola ranged as follows for each % Et_c treatment: kenaf (%); 25 (36–42), 50 (49–62), 100 (84–94), 125 (111–125), 150 (137–156) and canola (%); 25 (26–33), 50 (38–56), 100 (68–106), 125 (109–153) and 150 (157–180). Selected weather data and total water applied during the studies are reported in Table 1.

In-line turbulent flow emitters in the drip tubing were spaced 45 cm apart and had a nominal flow of 2 l h^{-1} at a working pressure of 130 kPa. Water applications were automated with solenoid valves and an irrigated controller and monitored using flow meters (Sensus Technologies Inc., Uniontown, PA). Irrigation cycles were scheduled in 7-day intervals. Weather data for the previous 7 days was downloaded from the CIMIS station. The sum of the Et_o losses were then multiplied by the cotton for canola K_c. These calculated water losses were used to determine the amount of water to be applied in the next 7 days. After the irrigation cycle, water readings were taken and the actual water applied was determined. Any adjustments necessary were made to the next 7-day irrigation cycle to maintain the irrigation treatments.

Nitrogen (applied as 20% CAN-17 solution; ammoniacal N (5.4–5.8%), nitrate N (11.2–11.6%) and Ca (7.6–8.8%)) and phosphorus (applied as 10% phosphoric acid solution) were injected weekly with the smallest irrigation treatment into the drip system over the growing season using Venturi-type (Mazzei Injector Corp., Bakersfield, CA) and proportional flow (Howard E. Hutchings Co., Visalia, CA) injectors, until a total of 135 kg N ha^{-1} and 41 kg P ha^{-1} had been applied. The fertigation injection took place toward the end of the irrigation cycle to ensure the crop would have available nutrients.

Both kenaf and canola were harvested 10–14 days after the onset of flowering during each respective growing season to maximize vegetative yield before any leaf abscission occurred. Although canola would usually be harvested for its seed products and kenaf for its stalk (core and bark fibers), we were interested in producing vegetative material from both crops. Plants with a large amount of leaf biomass may be more effective in removing water extractable Se in phytoremediation, and their leaves can be readily utilized as green forage. Subsamples were collected from each species at harvest by sampling two 2-m sections of the two center beds in each replicated

Table 1
Weather data and total water applied at different levels to kenaf and canola during the 1994–1999 growing seasons

Year	Crop	Mean air temperature (°C)	Total Et_c (mm)	Total rainfall (mm)	Total water applied as irrigation to each treatment (% Et_c)[a] (mm)				
					25	50	100	125	150
1994	Canola	12	136	108	37	52	92	148	213
1998	Canola	13	188	78	49	87	158	217	309
1999	Canola	17	308	42	101	174	326	472	554
1995	Kenaf[b]	21	919	39	330	450	860	1075	1368
1996	Kenaf[b]	23	886	29	369	448	782	1109	1381
1997	Kenaf[b]	22	1086	15	405	671	909	1205	1490

[a] Values are approximate; actual values of Et_c are provided in Section 2.
[b] Same amount of water was applied to all cultivars and breeding lines of kenaf.

plot. By using the two center beds, any potential interactions from nearby treatments were minimized. Plants were counted, composited and 12 plants were randomly selected, respectively, from each kenaf cultivar and breeding line or from canola. Samples were washed, oven-dried at 70 °C for 7 days and total shoot, stem (or stalk), leaf and root biomass were weighed. The outer bark and core materials were also separated from kenaf stalks and weighed. Perennial rye grass (*Lolium perenne* L.) was planted after each harvest to equilibrate soil moisture availability in the field between studies.

Unfortunately, portions of the soil water content data were lost during technician transition and thus, these data are not reported.

2.1. Statistical analysis

The experiments were completely randomized designs with four replicated plots per treatment. There were five irrigation levels × five cultivars/breeding lines for kenaf and five irrigation levels × one variety for canola. Analysis of variance (SAS general linear model procedures, SAS Institute Inc., 1988) was used to analyze the data and mean comparisons were made using the Duncan's multiple range test (Gomez and Gomez, 1984).

3. Results and discussion

3.1. Kenaf

The cultivars and breeding lines of kenaf were harvested September 15, 1995, September 1, 1996 and September 27, 1997. For all cultivars, kenaf required 780–1200 mm of water (100–125% Et_c) to maximize total shoot DM production (Fig. 1). Shoot yields from kenaf were at least equivalent or greater than total yields reported for other kenaf varieties ($\approx$15 metric tons dry weight ha^{-1}) (Bhangoo and Fernandez, 1991; Bhardwaj et al., 1995). Among the cultivars tested, C-531 generally produced significantly more shoot biomass than the others (Fig. 1). Biomass yields, however, do depend upon plant density, date of harvest and amount of water applied, as shown in this study.

Root DM was examined in two leaf types of the tested kenaf—a cordate leaf, Everglades-41, and a palmate leaf, Tainung-2. Both cultivars produced more roots at higher water applications (Fig. 2). It appears that kenaf has a prolific root system that is highly responsive to changes in soil water content (Muchow and Wood, 1980).

The proportion of total shoot biomass allocated to stems in kenaf was only significantly affected by irrigation at the lowest level of Et_c and was not significantly different among varieties (Fig. 3A). The ratio of bark:core fibers was also little affected by irrigation treatments, but did differ among cultivars (i.e. Everglades-41 had a significantly higher bark:core fiber ratio than the other kenaf tested; Fig. 3B). Thus, the amount of carbon allocated towards bark and core production appears to be unaffected by the total amount of water applied, except at the lowest irrigation level, the only level at which plants were exhibiting visual symptoms of water stress (e.g. stem elongation and leaf abscission). The total amount of photosynthate allocated to bark and core material, however, may differ depending on the cultivar of kenaf grown.

For this study, water use efficiency (WUE, defined in this study as biomass yield divided by the total amount of water applied), decreased for kenaf as the level of irrigation was increased from 25 to 150% Et_c (Table 2). This decrease is common for many species, including cotton and corn (Howell, 2000) and is partially due to increased evaporation and deep percolation losses at the higher irrigation levels. Thus, tradeoffs between maximizing production and reducing WUE need to be considered carefully when scheduling irrigation.

3.2. Canola

Canola was harvested January 15, 1994, February 14, 1998 and March 1, 2000. Production was lower during the first growing season than during the following seasons (Fig. 4). This was possible because of a shorter growing season and conditions were wetter (more cloud-covered days) and cooler in the fall of 1994 than in the fall of 1998 and 1999 (Table 1). However, despite seasonal

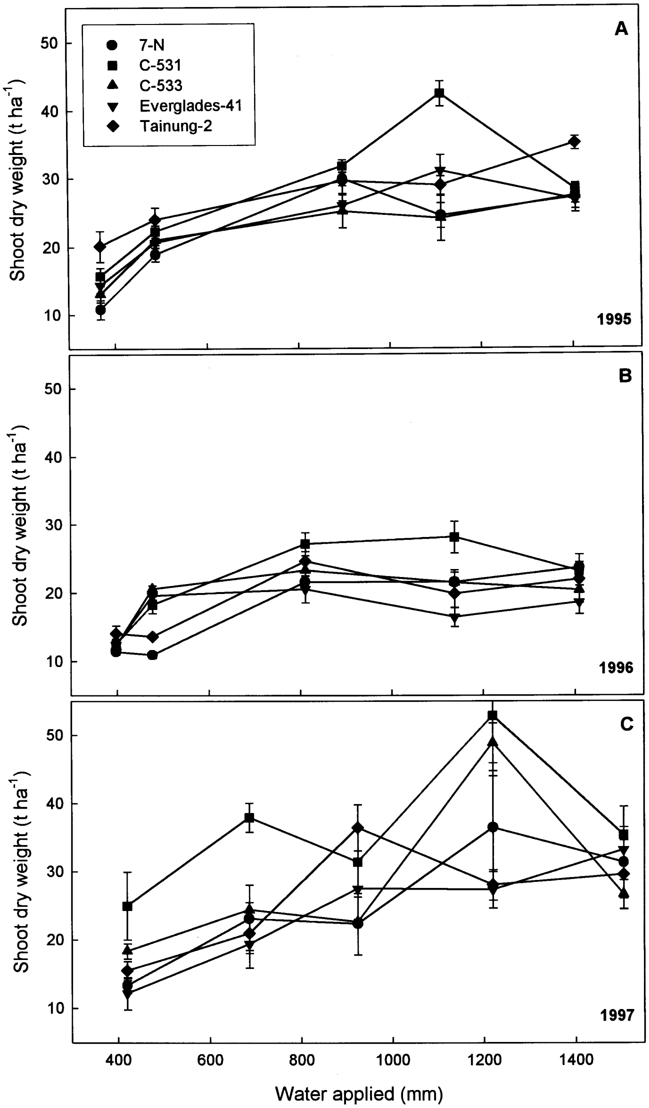

Fig. 1. Mean (± 1 S.E.) shoot dry weight of five cultivars of kenaf grown at five different levels of irrigation (water applied as irrigation plus precipitation) during the 1995 (A), 1996 (B) and 1997 (C) growing seasons. Shoot dry weights were significantly affected by irrigation, variety and irrigation $\times$ variety interactions at each harvest ($P < 0.01$), $n = 4$.

differences, shoot DM significantly increased as more irrigation water was applied, particularly in 1998 and 1999 (Fig. 4). Others have also observed higher DM production with irrigation in various Brassica spp. (Mingeau, 1974; Clarke and Simpson, 1978; Prihar et al., 1981; Singh et al., 1991), particularly during pre-flowering ((40–45 DAP) (Mathur and Tomar, 1972)). Overall, canola and other Brassica spp. appear very responsive to soil water availability. For example, in Alberta, Canada, canola grown for forage yielded 19 metric tons dry weight ha^{-1} during a wet year (Henkes and Dietz, 1995), which is almost twice as much as the best yields observed in this study.

Root DM production ranged from 1.9 to 2.6 metric tons dry weight ha^{-1} in the present study, but did not differ significantly among irrigation treatments (data not shown). In contrast, Kirkegaard et al. (1997) reported that rooting depth and root length density for canola and mustard were related to soil water availability in their study. Furthermore, Nielsen, 1994 (USDA-ARS, unpublished 1994 data) found that water stress during the second 5 weeks of growth for canola permanently limited root development. Apparently, water stress was not sufficient to affect root development of canola grown in the winter of the present study.

The leaf:stem ratios of canola increased with irrigation levels up to 200–250 mm of applied water (Fig. 5). Higher allocations of biomass to leaf tissue would be advantageous to growers

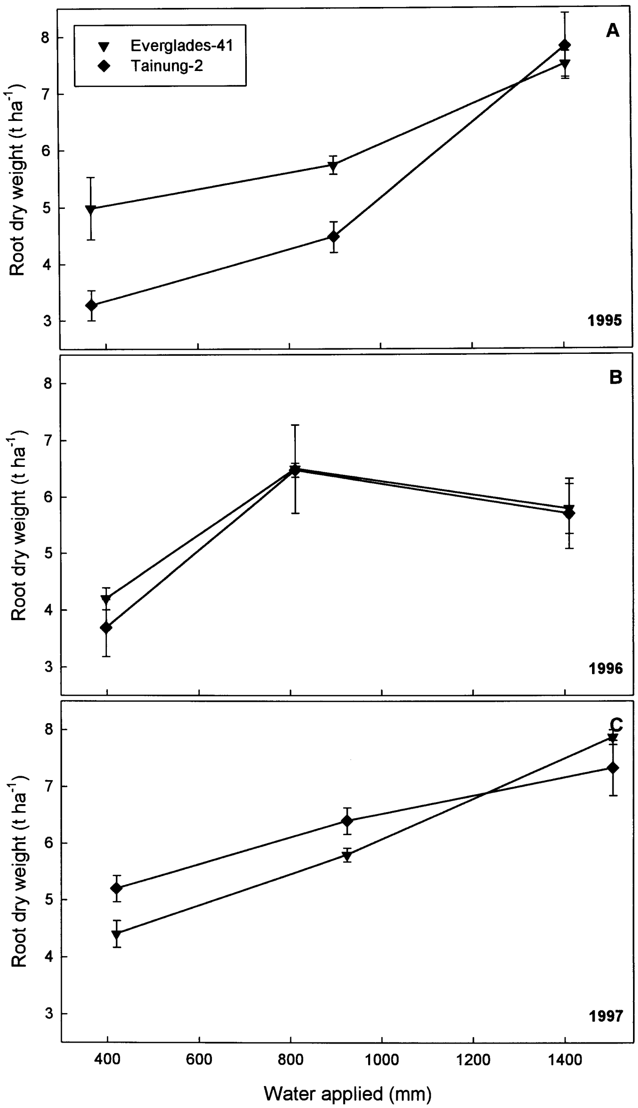

Fig. 2. Mean (± 1 S.E.) root dry weight of two cultivars of kenaf grown at three different levels of irrigation (water applied as irrigation plus precipitation) during the (A) 1995, (B) 1996 and (C) 1997 growing seasons. Root dry weights were significantly affected by irrigation at each harvest ($P < 0.01$). In 1995, root dry weights were also significantly affected by variety and irrigation $\times$ variety interaction ($P < 0.05$), $n = 4$.

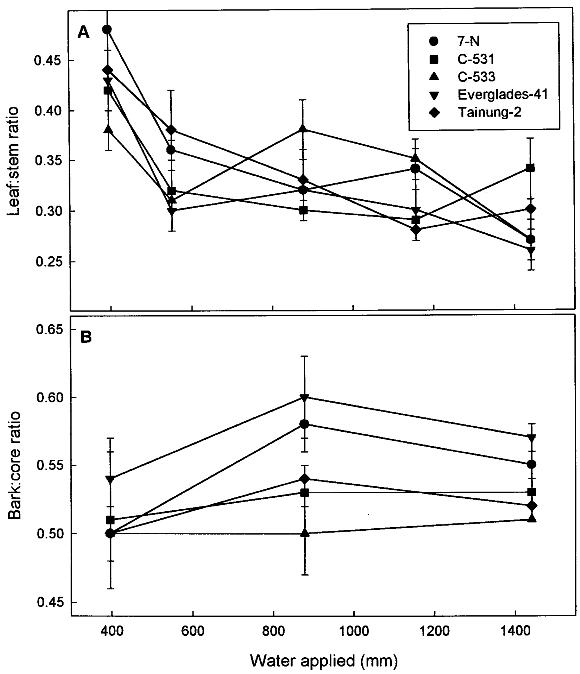

Fig. 3. (A) Mean (± 1 S.E.) leaf:stem and (B) bark:core ratios of five cultivars of kenaf grown at different levels of irrigation (water applied as irrigation plus precipitation). Data were pooled from the 1995, 1996 and 1997 growing seasons. Leaf:stem ratios were significantly affected by irrigation and irrigation × variety interaction ($P < 0.05$), whereas the bark:core ratios were significantly affected by irrigation and variety ($P < 0.05$), $n = 12$.

using canola as animal forage because canola leaves have higher nutritional value and are preferred by animals rather than stems (Wiedenhoeft and Bharton, 1994). Brassica leaves could potentially provide high quality herbage during the hot months of summer, as well as during the cool months of fall. High leaf biomass production is also beneficial when using canola for phytoremediation of Se because leaves accumulate the greatest amount of Se (Bañuelos et al., 1997).

The WUE of canola also decreased as the level of irrigation increased from 25 and 150% Et_c (Table 2), similar to kenaf. Interestingly, values of WUE were also similar on average between kenaf and canola at each irrigation level.

4. Conclusion

Total dry matter production was significantly increased by irrigation in both kenaf and canola using the crop coefficient developed for growing cotton in the San Joaquin Valley, CA. Kenaf was grown in warmer months (with a higher Et_o) similar to cotton and required considerably more water than canola, which was grown dur-

Table 2
Water use efficiency (WUE) values for kenaf and canola grown at five different irrigation levels during the 1994–1999 growing seasons[a]

Year	Crop	WUE at following irrigation treatment (% Et_c)[b] (kg/m^3)				
		25	50	100	125	150
1994	Canola	3.16	3.07	2.81	2.30	2.08
1998	Canola	4.97	3.98	3.36	2.49	2.10
1999	Canola	3.73	3.18	2.38	1.87	1.64
1995	Kenaf[c]	4.01	4.36	3.16	2.70	2.05
1996	Kenaf[c]	3.13	3.47	2.89	1.88	1.52
1997	Kenaf[c]	4.01	3.67	3.04	3.17	2.08

[a] WUE values (defined in this study as biomass yield divided by the total amount of water applied) were calculated from total biomass yields (Mg ha^{-1}) divided by the total water applied, including rainfall.

[b] Values are approximate; actual values of Et_c are provided in Section 2.

[c] Total biomass yields from all kenaf cultivars and breeding lines were used for calculation of WUE; same amount of water applied to all kenaf.

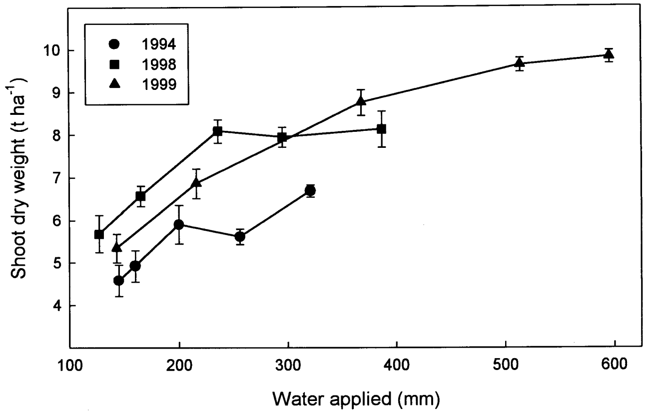

Fig. 4. Mean (± 1 S.E.) shoot dry weight of canola grown at five different levels of irrigation (water applied as irrigation plus precipitation) during the 1994, 1998 and 1999 growing seasons. Shoot dry weights were significantly affected by irrigation at each harvest ($P < 0.01$), $n = 4$.

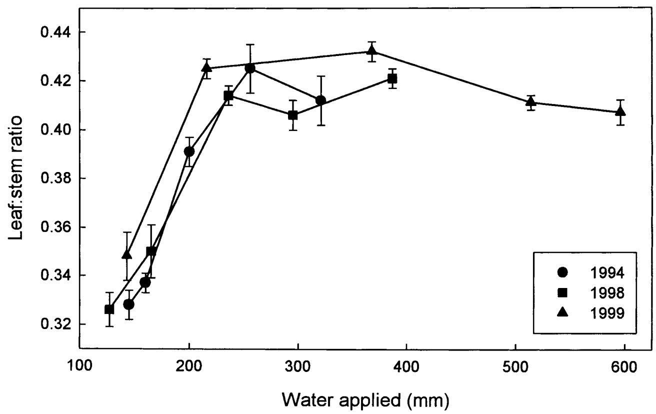

Fig. 5. Leaf:stem ratio of canola grown at five different levels of irrigation (water applied as irrigation plus precipitation) during the 1994, 1998 and 1999 growing seasons. Leaf:stem ratios were significantly affected by irrigation at each harvest ($P < 0.05$), $n = 4$.

ing cooler months for maximum vegetative growth. In the present study, kenaf required 780–1200 mm of water applied during irrigation or by precipitation for optimal growth and production, whereas canola required only 210–550 mm of water. Kenaf produced at least twice as much biomass as canola, irrespective of the irrigation treatment. The greater water requirement of kenaf could be a problem in areas where irrigated water is limited. Economics, water availability, soil conditions and product utilization will help growers decide if and when to grow kenaf or canola as an alternative irrigated crop in central California.

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